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Electronic Expansion of Human Perception

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Virtual Reality, as its name suggests, is an unreal, alternate reality in which anything could happen. In its 1991 technological implementation, Virtual Reality is a 3D video game you can enter by strapping something onto your face that fools your senses into perceiving an environment that surrounds you on all sides. The thing strapped to your face is called a Head-Mounted Display.

The true potential of this new field comes from the ability of a Head-Mounted Display to induce a synthetic experience in its wearer. The ability to artificially create and design experience enables possibilities and powers that were formerly impossible. If experience can be captured and transmitted, then you can "travel" instantaneously to a distant location and see the trees, feel the wind, hear the birds, and smell the flowers. If electronic instruments can sense things that you cannot perceive, such as the inside of opaque objects, then you can be shown images of these invisible things. If microscopes and tiny probes can scan and manipulate the microscopic world, then you can "shrink," like Alice in Wonderland, to enter into a three-dimensional world of palpable bacteria and Brontosaurian insects.

The true potential of the Head-Mounted Display, the piece of gear that has enabled Virtual Reality, is not that it allows you to enter into a fantasy world, but that it allows you new ways of perceiving the real world.

Expansion of Perception

Vision, hearing, touch, taste, and smell are the traditional five senses, and in addition, you have the ability to sense temperature, vibration, acceleration of your body, the positions of your limbs, forces acting on your body, hunger, thirst, pain, and other sensations related to your body's internal state.

There are, however, things which are invisible to all of your senses. Examples of these imperceptible phenomena are X-rays, infrared radiation, radio waves, magnetic fields, radioactivity, ultrasound, electricity, the inside of opaque objects, microscopic objects, and events occurring too fast to see. Even though you cannot directly perceive these things, you can indirectly measure and observe them with various instruments and electronic sensors.

By linking electronic sensors to a Head-Mounted Display, it is now possible to create "sensory transducers," which will allow you direct perception of these phenomena which are imperceptible without electronic augmentation. As an example, night-vision goggles allow you to see and move about in total darkness by amplifying the low levels of light that are actually present. Sensory transducers can be built to make visible radioactivity, or any other invisible phenomenon for which electronic sensors exist.

Ultrasound scanners are currently used to look into the human body, and by connecting these scanners to a Head-Mounted Display, it will soon be possible to see directly into the living tissue. By using half-silvered mirrors, the Head-Mounted Display can allow you to see through to the real world, with the image from the ultrasound scanner optically superimposed. Thus, an obstetrician examining a pregnant woman could see the woman, feel the fetus kick beneath his hands, and see the ultrasound image of the fetus appearing to hang in space inside of her belly. We call this "X-ray vision," by analogy with Superman's ability to see inside of solid objects, even though it is ultrasound rather than X-rays than would actually be used. Figure 1 shows a drawing of this set-up.

We are working towards building a prototype of such a device here at the University of North Carolina. My colleagues Henry Fuchs, John Poulton, John Eyles and their team have over the last ten years built high-performance graphics computers (Pixel-Planes) that make it possible to compute views of two- and three-dimensional medical image data in real-time. My colleague Steve Pizer and his team have for fifteen years been developing algorithms and systems to make computer graphics an effective tool for radiologists and radiation oncologists. The volume rendering technique they have developed will be useful for displaying 3D ultrasound image data. My colleagues Jannick Rolland and Rich Holloway are designing the optics and software for a see-through Head-Mounted Display for medical use. We hope to have this prototype of the X-ray vision goggles working in the next year or so.

A Head-Mounted Display must be head-mounted because your eyes, ears, nose and tongue are head-mounted. Your senses are directional, and the location in space from which sensory inputs originate is an important part of your perception of the world around you. Seeing or hearing a nearby rattlesnake with your natural senses implies knowing where it is relative to your body. A Geiger counter that warns you when radiation is present is better than nothing, but a head-mounted sensor that lets you see radioactive gas leaking through the wall is a vast improvement in awareness.

What do these imperceptible things look like? Well, they don't look like anything -- they're invisible. A visual representation must be invented. This is a graphic design problem. What does radiation look like? Perhaps it is purple, with a brightness that indicates its lethality.

It is useful to consider earlier efforts to portray the invisible. What does a molecule look like? Since atoms are a thousand times smaller than the wavelength of light, molecules have no visual appearance, and so an appropriate graphical representation must be created. (The appearance of a molecule under an electron microscope is not a definitive answer to what a molecule looks like, but rather a technologically convenient choice of a visual representation.) Figure 2 shows two different depictions of the same protein molecule -- one representation emphasizes how the molecule fills space, while the other shows only the path of the proteinUs polypeptide backbone as it winds through space.

Figure 2. Caption What does a molecule look like?
Two representations of dihydrofolate reductase.
(a) touching colored spheres
(b) ribbon backbone

My colleague Fred Brooks has for more than fifteen years here at the University of North Carolina been putting computer graphics to work to help biochemists understand the structure and properties of the large organic molecules they study. These representations are ones that have proved informative to the biochemists.

What does human speech look like? Casting speech into visible form is something you take for granted: it is called writing. Various innovations occurred over the last five thousand years -- the invention of the alphabet, spaces between words, the printing press, and standardized spelling. Writing is now a mature art, and the link between the sounds of speech and the black marks on a page of a book are quite abstract. Figure 3 contrasts (a) a sonogram, a straightforward way to visualize vocal sound, with (b) the much more abstract form of modern written language.

Figure 3 Caption: What does speech look like?
(a) sonogram
(b) English prose

Reading is, in a sense, hearing with your eyes. This cross-sensory substitution is closely related to a sensory transducer for the imperceptible. For the deaf, the sound of human speech is an imperceptible phenomenon. If it were possible to make a device that, in real-time, converted speech to written text, then this device would, in effect, allow a deaf person to hear. This capability -- real-time, speaker-independent, continuous speech recognition -- has not yet been achieved. It ought to be possible, nevertheless, to create some kind of real-time visual representation of the sound of speech that, when visually superimposed on the movements of the lips and face, is sufficient to allow a deaf person to comprehend what is being said.

What does computation look like? The step-by-step actions of a computer as it manipulates data under the control of a program is a dynamic process that could be given an animated graphical representation, but there is currently no widely-used or accepted depiction of the process of computation. Computation is currently invisible.

The electronic expansion of human perception has, as its manifest destiny, to cover the entire human sensorium. Ultraviolet rays that will cause a sunburn hours later might be mapped to an insistent vibration on the skin. Dangerous radiation which would kill you in a few minutes might be signaled directly with purposely-induced pain. If each computer instruction were mapped to its own audible frequency, then each computer program would, because of its characteristic sequence of instructions, make its own recognizable sound. And, as Julius Smith of Stanford has suggested, if design rule violations were mapped to smells, an engineer could turn to his colleague's circuit diagram and truthfully say, "This design stinks."

Real-Space Databases

Information is often associated with location. Maps, inventories, and mailing lists are, in essence, lists of information about objects and features at specific locations.

Using a see-through Head-Mounted Display which tracks its location in the world, graphical data files could be spatially registered with the real world. A particular graphic object from the data file would be seen sitting at one spot in the world, and nowhere else. The data file would give the coordinates of the object's location -- a very accurate latitude, longitude, and height above sea level -- and only at that location could it be seen. Michael Naimark, a media technologist in San Francisco, has coined the term "real-space imaging" to describe graphics that are registered with the real world, just as real-time graphics are synchronized with events in the real world.

To find a specific item whose location in a company's huge warehouse is known, a huge red blinking arrow could appear in the air above the item, always remaining above it as you approached. Ghostly computer graphic labels could be attached to real-world objects and places. At specific places, you could leave notes to yourself that only you could see. ("Don't eat at this place again.") You could leave warnings for others or scrawl rude graffiti.

The difference between these virtual labels and real physical ones is that everyone can see physical labels, whereas each virtual label exists in some spatial data file and can only be seen if you have loaded that file into your Head-Mounted Display. This means, unfortunately, that virtual billboards will probably not replace the physical ones that line the highways -- they would be too easy to turn off. To guide you to her house, a friend might give you, not written directions or a map, but a spatial data file that had a huge orange stripe hovering ten feet above the road along the route from your house to hers. It would be difficult to miss a turn at an intersection where the huge orange stripe above you veered to the right.

Geographical information systems, which have become popular lately, are in essence computerized maps. Information is displayed in a spatial distribution that conforms with the spatial distribution of the real-world objects the information describes. If such a computerized map is enlarged and superimposed onto the real world, then it becomes a real-space database.

A real-space graphical model of a building could be created on-site, before construction began, to see what the building would look like in its real surroundings. Figure 4 shows a drawing of this. An architect and client could walk through a simulated house at its planned site, looking through simulated windows at the real trees surrounding the site. The architectural walk-through team here at the University of North Carolina, led by Fred Brooks, has for several years been building detailed computer models of buildings and exploring the questions of how realistic the models need to appear, how the user can move through them, and how they can be segmented.

The plans and maintenance instructions for a complex mechanism such as an aircraft's jet engine could be spatially superimposed on the engine being repaired, with the engine's self-diagnostic circuits causing a large red arrow to point to the particular part that required replacement.

In time, a huge number of real-space databases will come to exist, and just as you must choose which books you will read, you will have to choose which graphic databases, if any, you wish to overlay onto the world.

Remote Presence

Being somewhere, from an experiential point of view, consists of being able to look around at the things that surround you, to touch them, to walk around, and to hear, feel, and smell whatever is present with you. If the light, sound, and other physical phenomena which trigger your senses can be detected electronically and transmitted to a Head-Mounted Display, then it is possible to have the experience of being at a place when in fact your body is many miles away. This technological out-of-body experience is called "telepresence."

The experience of simulated presence at a distant place is, in fact, very familiar to each of us. When using a telephone, your voice and ears are electronically linked to those of a distant person, and you converse as if you were in the same room. This is auditory telepresence. It seems very natural and normal.

To have the visual experience of a 3D world that surrounds you, it is necessary to see with both your eyes and to be able to look around. The technical implementation of visual telepresence is to feed the signals from a pair of video cameras to the left- and right-eye fields of a Head-Mounted Display, with the cameras mounted in a robot head whose motion mimics that of your own head. When you turn your head, the robot head turns. And since you see what the robot head sees, when you look around, you see the environment that surrounds the robot. The "Green Man" is a robot built for underwater remote presence research by the Naval Ocean Systems Center in Hawaii. (It is called the Green Man because its movements are hydraulically actuated, and the green hydraulic fluid drips from its hoses as if it were green alien blood.)

In addition to cameras slaved to the motion of your head, the Green Man also has robot arms slaved to the motions of your own arms. By putting on the gloves and headset that link you to the distant robot, your senses are transported into the robot body. If your eyes and hands are at a remote location, you're there.

When you control such a telepresence robot from a distance, you can see, hear, and converse with another person in front of the robot. The person you talk to, however, would not see you, but rather a slimy green robot that was gesticulating and talking with your voice.

In a telephone conversation, each person has a microphone and a speaker in the telephone handset, with each microphone linked to the other person's speaker. The analogous setup for visual telepresence is for each person to wear a see-through Head-Mounted Display which is linked to a telepresence robot at the location of the other person. In such a conversation, you would see the other person's face superimposed onto the robot face which was physically there before you. You could thus have a "face-to-face" conversation with a distant person, achieving eye contact and observing one another's facial expressions.

The telephone allows electronic ventriloquism. It lets you throw your voice, at the speed of light, to any location where you can coax someone to pick up the receiver. Likewise, visual telepresence will allow you to project your eyes, at the speed of light, to any location where a telepresence robot exists. This is instant travel. An executive might in ten minutes do his daily tour of the warehouse, the factory, the lab and the accounting department, even though these places are thousands of miles apart.

The robot hands of the telepresence robot allow the human operator to manipulate objects at the robot's location. This goes beyond the mere passive sensory "presence" at a remote location and therefore has a different name -- "tele-operation." In extremely dangerous environments, mortal human beings can be replaced with human-controlled tele-robots. The Green Man was designed to work on the bottom of the ocean, too deep for divers. NASA may use tele-operated robots to construct its space station. Tele-manipulators are used to handle the radioactive fuel in nuclear reactors. Tele-operated robots are beginning to be used to fight fires and to defuse bombs.

Micro-Tele-Operation

Tele-robots don't have to be the same size as their human operators. Tele-robots the size of King Kong could be made, say, for constructing buildings. Tiny tele-robots could also be made. As operator of a micro-tele-robot, you would have the perception that the ordinary world had expanded enormously, or equivalently, that you had been miniaturized. Operating at a 1-to-100 scale factor, the micro-robot would be two centimeters high and you would perceive a mouse to be the size of an elephant.

Some work has already been done in micro-tele-operation. A scanning-tunneling microscope can image individual atoms, detect surface forces as it probes these atoms, and move atoms around with its probe; at an IBM lab in Yorktown Heights, New York, researchers have hooked up such a microscope to a force-feedback device to make it possible to "touch" atoms. Controlling micro-robots is one of the goals of Dr. Tachi in Tsukuba Science City, Japan, who is one of the leading researchers in one-to-one scale tele-operation.

It is not necessary to make smaller and smaller self-contained robots to achieve micro-tele-operation. With a microscope and micro-manipulator, you could effectively have your eyes and hands projected into the microscopic world. And to perceive that the micro-world surrounded you, when you turned your head, the microscope would need to swivel around the specimen to achieve the right point of view. Another way to achieve quick changes of point of view in the micro-world would be to mount the specimen on an electrically-controlled rotation stage beneath the lens of a fixed microscope. This approach assumes a micro-world that is relatively transparent, such as a drop of water from a pond, so that any internal point of view can be achieved, even though the microscope looks in from the outside.

Scaled down by a factor of 100, you could reach out and tweak the antenna of a honeybee that you perceive to be four feet long, as shown in Figure 6. And it couldn't sting you.

An effective micro-tele-robot could be used for micro-surgery. An adventurer could take a microscopic safari into an anthill to battle the furious hordes of ants. As people begin to work and play in micro-worlds, a need will arise for microscopic tools and devices which will perhaps be manufactured using micro-tele-robots.

Virtual Reality will prove to be a more compelling fantasy world than Nintendo, but even so, the real power of the Head-Mounted Display is that it can help you perceive the real world in ways that were previously impossible. To see the invisible, to travel at the speed of light, to shrink yourself into microscopic worlds, to re-live the experiences of yourself and others -- these are the powers that the Head-Mounted Display offers you. Though it sounds like science fiction today, tomorrow it will seem to you as commonplace as talking on the telephone.

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